

A Search for Circumstellar Companions Around Nearby White Dwarf Sirius b

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ABSTRACT

1. INTRODUCTION

Very little is known about the evolution of planetary systems beyond the main-sequence lifetime of their host stars. Theoretical calculations show that planets can survive the red giant and asymptotic giant stages (Burleigh et al. 2002; Jura 2008; Nordhaus & Spiegel 2013), and results from radial velocity and transit surveys suggest extrasolar planets are prevalent throughout the Milky Way (Cumming et al. 2008). However, only one planetary mass object has been detected around a white dwarf (WD) with imaging (WD 0806-661; Luhman et al. 2011).

Directly imaging exoplanets is a powerful method in exoplanet science which explores a parameter space very complementary to the popular transit photometry and radial velocity methods. The red giant stage has cleared planets within a few au greatly lowering the transit probability. White dwarfs have very few spectral lines to make high-precision radial velocity measurements from spectral lines. Imaging, though, benefits from the orbital expansion of the planet, and the cooling of the white dwarf greatly reduces the contrast between them (Burleigh et al. 2002; Gould & Kilic 2008). The Degenerate Objects around Degenerate Objects (DODO) survey observed 29 white dwarfs with Gemini/NIRI and VLT/ISAAC and provided upper limits around $\sim 8 M_J$ beyond 35 AU (Hogan et al. 2009).

In this work we study the closest white dwarf to the Sun, Sirius b, and provide upper mass limits based on our observations in the near-infrared. [section 2](#) describes our target and observing strategy, [section 3](#) describes the processing and analysis techniques used, [section 4](#) describes our results and we conclude with [section 5](#).

2. OBSERVATIONS

Sirius is the closest star system to the Sun at 2.7 pc away, consisting of an A1Vm star (a) and a WD with an age around 225 Myr (Bond et al. 2017; Collaboration et al. 2018). There are no known planets around either star, and using constrained 3-body numerical simulations a potential companion around Sirius b would only be stable with a 1.79 yr orbit, which corresponds to a circular orbit with 1.5 AU separation. Sirius b has been studied in the 10 μ m regime recently by Pathak et al. (2021), who achieve 1.8 M_J to 3.5 M_J upper limits within 2 arcseconds.

We targeted Sirius b directly using Keck/NIRC2 in Lp-band across three epochs in 2020 [Table 1](#). Due to the high proper motion and reasonable orbital motion, we started by calculating the projected offset and position angle from Sirius a based on the orbital parameters from Bond et al. (2017). We first slewed to Sirius a, which is easy to lock onto due to its brightness (-1.35 K-band magnitude; Bonnet-Bidaud & Pantin 2008). We found that Sirius b is too dim (9.01 K-band magnitude; Bonnet-Bidaud & Pantin 2008) for the adaptive optics (AO) performance necessary for coronagraphy and that the scattered light from Sirius a was detrimental to closing the AO loop when using Sirius b as a natural guide star (NGS) anyways. Therefore, we employed a unique off-axis solution, using a narrow laser-line filter for the wavefront sensor using Sirius a as the NGS and offsetting to Sirius b manually.

The scattered light from Sirius a is so strong, in fact, that radial diffraction spikes from the Keck II secondary mirror support structure are still present in the Sirius b frames, which reduced our overall observing efficiency due to discarding these frames. An example of such a diffraction spike is shown in [Figure 1](#).

3. ANALYSIS

Table 1. Observing parameters for the three epochs of data. All observations were carried out using the NIRC2 Lp-band filter. Observation time is based on the frames that were selected for processing.

Date observed	Sirius a offset (")	Sirius a PA (°)	Observation time (hr)	Seeing (arcsec)	Temp (°C)	PWV (mm)
2020-02-04	11.20	67.90	1.44			
2020-11-21	11.27	66.42	2.91			
2020-11-28	11.27	66.38	2.44			

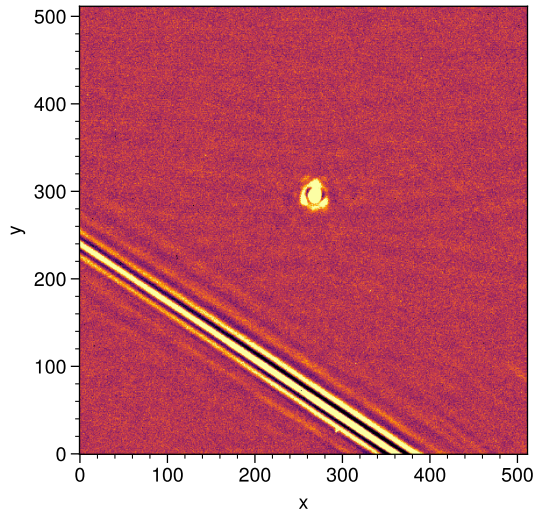


Figure 1. Calibrated science frame of Sirius b from 2020-02-04 epoch showing the strong scattered light effects from Sirius a.

For each epoch we applied a flat correction using calibration frames captured during observing. We also removed bad pixels using a combination of L.A.Cosmic (Dokkum & G 2001) and an adaptive sigma-clipping algorithm. We finally remove sky background using

a high-pass median filter. Each frame is co-registered and aligned with the center of the FOV and lastly cropped to the inner 200 pixels. With the pixel scale of 10 mas/px the crop corresponds to a maximum separation of 2.7 AU. We also measure the parallactic angle of each frame, including corrections for distortion effects following Yelda et al. (2010).

We apply the technique of angular differential imaging (ADI; Marois et al. 2006) where we disable the field rotator and allow the FOV to rotate throughout the night as Earth rotates. This apparent rotation isolates systematic noise from the telescope, which includes the point-spread function (PSF). By modeling and subtracting the PSF before derotating the frames to a common direction, potential companion signal is preserved since it does not appear stationary in the

4. RESULTS

5. CONCLUSIONS

Software: ADI.jl (Lucas & Bottom 2020), astropy (Collaboration et al. 2013; Astropy Collaboration et al. 2018), Julia (Bezanson et al. 2017), numpy (Harris et al. 2020), scikit-image (Walt et al. 2014),

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